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EXPERIMENTAL TESTING OF A FULL-SCALE OF GROUP EFFICIENCY IN MULTIPLE SOIL LAYERS

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Abstract

Results of in-situ tests showed that the performance of single isolated piles and individual piles within a group is largely different. When piles are arranged in a group, the interaction between piles and the foundation depends on the pile arrangement and the pile group effect. To date, studies on the pile group effect in Vietnam have been limited to reduced-scale laboratory testing or static load testing where piles are installed into homogeneous sandy or clayey foundation. This paper presents in situ tests which were performed on both single piles and pile groups, loaded to failure, with the aim of studying the pile group effect of piles embedded in multi-layered foundation. Strain gauges were installed along the shaft of 10 m long steel pipe piles, with a diameter of 143 mm. The influence of loose sand layers on the group effect in case of friction piles was evaluated. The experimental results indicated that the influence of sand layers was evident, and the group factor was calculated to be 1.237.

Keywords: group efficiency; pile groups; axial capacity; load transfer.

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1. Introduction

Pile group effect is the effect of mutual interaction between piles in a group through the foundation, having influence on the general load capacity of the pile group. The interaction between piles in a group can result in two types of effect (1) to alter (mainly reduce) the load capacity of the entire group compared to the total load capacity of individual piles; (2) group effect, increasing the stress transmission area, causing the settlement of the pile group much higher than the single pile, especially when there is a soft soil layer near the pile tip. Pile group effect appears very differently between different types of piles and different types of soil. The influence of the group effect is often shown clearly in the friction pile group when the piles are close to each other and the soil is clayey.

There have been many studies on pile group effect ([1–6]) that studied the subsidence of pile group, based on various approaches, including the methods of boundary element, load transfer and finite element. There has been much progress in analyzing and predicting the pile group effect over the past few decades, but the analysis is still largely based on simplification of the problem and behavior of the soil. Due to the difficulties and costs of 1:1 model load test, most pile group tests have been performed on miniature models in situ or in the laboratory [7].

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Ismael [8] studied behavior of bored pile groups in cement sand by in-situ tests. The compression tests were conducted on two pile groups, each group consists of five piles. The spacing of piles in the groups was two and three diameters. The pile group effect determined from the tests was 1.22 and 1.93, corresponding to the pile spacing of two and three times of the pile diameter. Al-Mhaidib [9] studied the behavior of pile groups in sandy foundation under different load levels. A total of 60 tests were conducted in the laboratory, using a model of small diameter steel piles, placed in medium tight sand. The sample piles had an outer diameter of 25 mm and a length of 500 mm in the soil. Five ways of arrangement of piles in the group (2×1, 3×1, 2×2, 2×3, 3×3) with the pile spacing $3d, 6d$ and $9d$ (d is the pile diameter) were tested.

Deb and Pal [10] carried out testing on 1×1, 2×2 and 3×3 pile group models, with the ratio of length in soil to diameter (L/D) of 5, 6, 7, 8 and the distance between the piles equalling 3 times of the diameter, subject to vertical load. The sample piles used for testing had a length of 250 mm with a diameter of 25 mm. Elsamny et al. [11] studied load bearing capacity and behavior of piles in sandy foundation for single piles and group of two piles under axial compressive load. Experimental research was carried out to study axial friction distribution and load on pile heads, in non-clayey soil (tight sand), as well as group effect of two piles. The distance between piles was three times of the pile diameter. The calculated pile group effect was 1.43.

Yudiawati et al. [12] studied pile group effect and the efficiency of friction piles on very weak clay foundation, which were performed by static compression of friction piles in very soft clay. The test piles consisted of square concrete piles of 20 cm × 20 cm, with the length of 11.5 m and 17.5 m. The pile groups included 2×2 piles and 3×3 piles, with spacing between piles of 3 to 5 times of the pile diameter. Load tests were conducted on single piles (2 experiments), on individual piles in a group of piles (5 experiments) and on a group of piles (4 experiments). The results showed that load bearing capacity of a single pile, in general, was higher than capacity of individual pile in a pile group, so the coefficient of pile group effect found ranged from 50% to 70%.

According to Tomlinson and Woodward [13], axial load capacity of a pile group may be significantly smaller than total load capacity of individual piles in a group. In all cases, elastic and consolidation settlement of a pile group is larger than the settlement of a pile that bears the same load as on individual pile in a group. This is because the subsidence area of the pile group extends to a wider width and depth than the area below the single pile.

In previous studies, experimental studies were mainly conducted with homogeneous foundation, loose soil or cohesive soil. In the scope of the paper studying the pile group effect in case of multi-layered foundation, especially the effect of porous, medium-tight sand layers in the foundation on the load bearing capacity and subsidence of friction piles, the following issues are clarified: (i) coefficient of pile group in multi-layered foundation, with sand and clayey soil layer; (ii) distribution of forces along the pile shaft; (iii) effect of pile group on settlement of the pile group.

2. Testing models

In this study, static load tests are carried out on natural ground at the 2nd campus of National University of Civil Engineering in Phu Ly city, Ha Nam province. Testing models include: (i) static load test for single piles; (ii) static load test for a group of 4 piles with spacing of pile center - pile center $\Delta = 3.5D$ (D is pile diameter). All tested piles are steel pipe piles with outer diameter (D) of 143 mm, thickness (δ) of 6 mm, all piles have the same length (L_{Pile}) of 10 m, steel strength (E_0) of 2.1 kN/cm^2 for both piles and pile caps. Single pile testing area is about 4 m away from the testing area of pile group (Fig. 1). In this study, tests with single piles are denoted by N°1, tests with a group of 4 piles are denoted by N°4, the index after N°4 indicates a specific pile in that group.

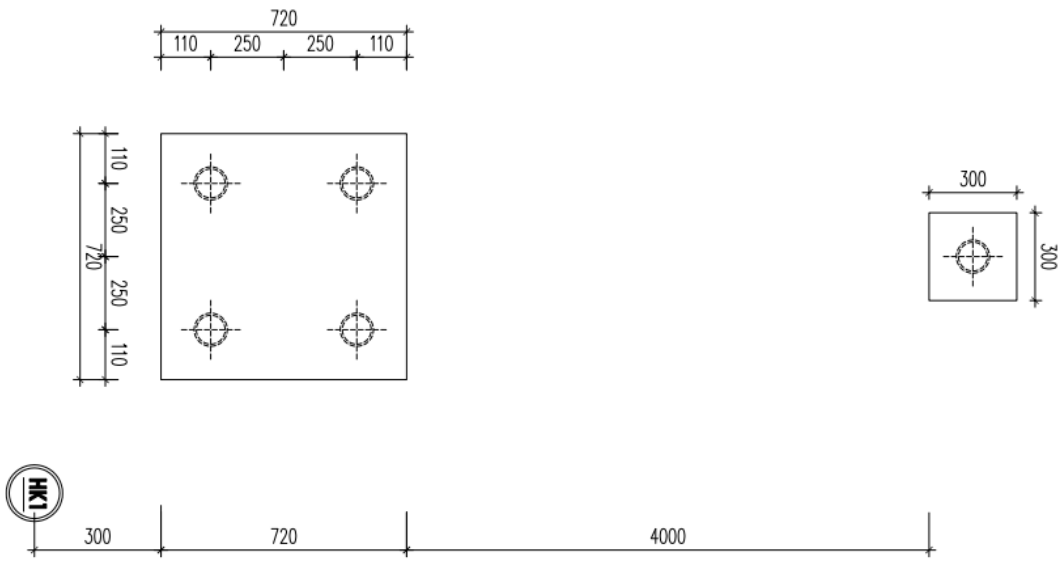


Figure 1. Arrangement test piles, (i) single piles, (ii) group of 04 piles, survey drilling position

Stratum in the testing area is determined from the geological survey results. A hole is drilled to a depth of 20 m at the testing area. Standard penetration tests (SPT) and laboratory tests have been carried out to determine the mechanical and physical properties of soil. Drilling results show that strata consist of the following soil layers: Layer 1, covering soil, leveling soil, composition and status are heterogeneous, compacted, 3.0 m thick; Layer 2, clay mixed with organic matter, brown gray, mahogany brown, quasi-plastic state, 1.0 m thick, SPT (N_{TB}) = 4; Layer 3, dust, ash gray, brown gray, porous texture, 2.7 m thick, SPT (N_{TB}) = 8; Layer 4, brown-gray clay, mahogany brown, dark gray, quasi-plastic state, 1.4 m thick, SPT (N_{TB}) = 4; Layer 5, clay mixed with sand, brown gray, mahogany brown, quasi-plastic state, 9.9 m thick, SPT (N_{TB}) = 6. Underground water level is 0.7 m deep.

With the pile length of 10 m, the strata that piles go through include 5 layers of soil surveyed. Tests are carried out to study group effect, in the condition of multi-layered foundation, considering the effect of sand layers in the foundation. The piles are lowered by static jacking method. A steel plate of 0.7 m × 0.7 m dimension, 3 cm thick is placed on single piles and pile group as pile cap. Fig. 1 shows a layout of piles, single piles and pile group. The pile caps are located on the ground (not in contact with the ground), and can be considered absolutely hard. The axial load is transmitted along the piles, measured by strain gauges, uniformly installed on each section for all test piles. The gauge used in this study is Strain Gauges FLA-5-11. Fig. 2 illustrates the pile structure, the location for installing strain gauge along the pile shaft.

The first test was carried out 10 days after the initial pile driving. Tests are carried out according to the slow loading cycle (according to the Vietnamese standards TCVN 9393:2012), including 2 cycles, cycle 1, loading to 100% of the predicted load, cycle 2, loading to destructive one. Load increasing level is adjusted according to the actual test. The load is affected by hydraulic jacks, the meter reads exactly to 0.01 mm Settlement is measured at four positions on the top surface of the lid with four displacement sensors.

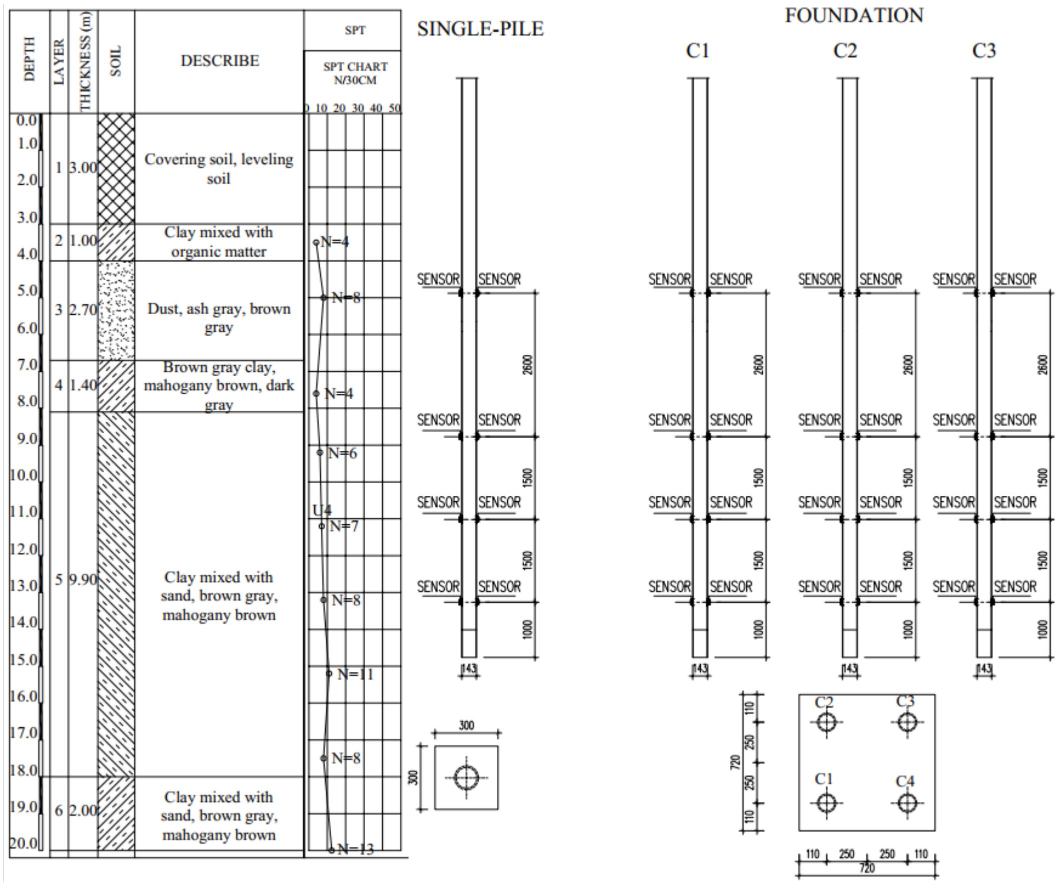
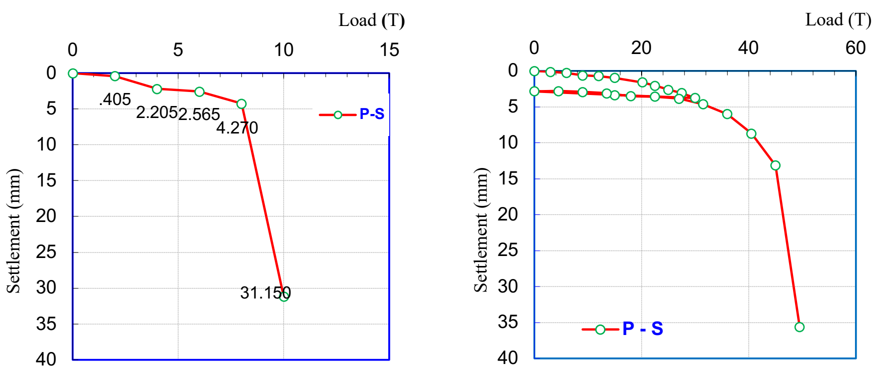


Figure 2. Geological pillar of testing area, pile structure, position of displacement sensor

3. Result analysis

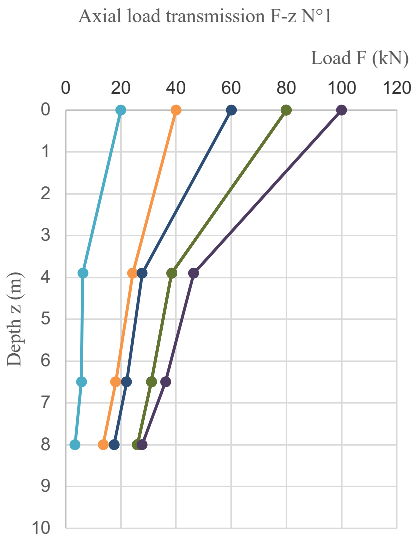
Test results include (1) subsidence corresponding to each load level, expressed by load-settlement curve (P-S) for single piles and group of 4 piles; (2) axial strain is measured by strain gauges with each effect load level, represented by the load distribution curve according to the depth (F-z). These results are shown in Figs. 3, 4 and Table 1.



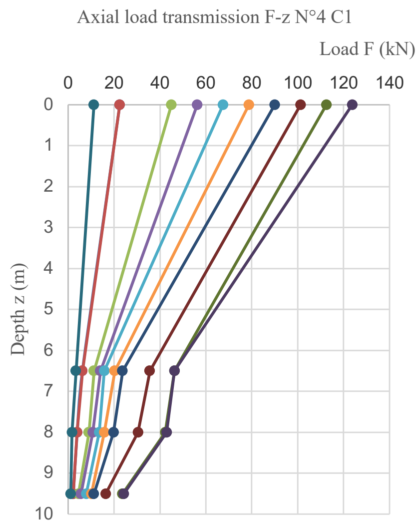
(a) Test for single piles N°1

(b) Test for group of 4 piles N°4

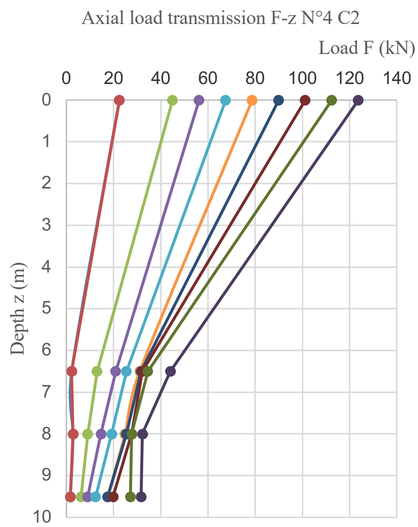
Figure 3. Load-settlement curve (P-S)



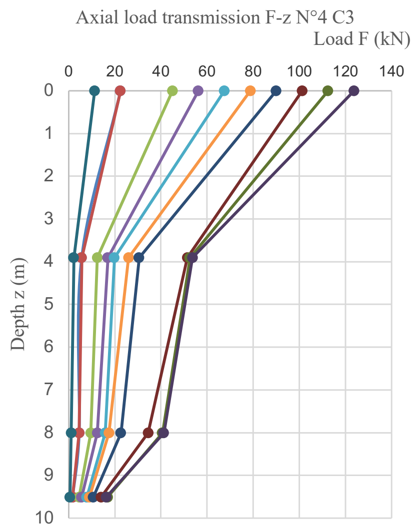
(a) For single piles



(b) For piles N°4 C1



(c) For piles N°4 C2



(d) For piles N°4 C3

Figure 4. Axial load transmission curve (F-z)

Fig. 3 shows the load-settlement curve (P-S) for single pile (Fig. 3(a)) and group of 4 piles N°4 (Fig. 3(b)). For single piles, test is carried out with the first cycle compressing to destructive to determine the limited bearing capacity of the pile. The ultimate bearing capacity of a pile is the maximum load which it can carry without failure or excessive settlement of the ground. The test results show that when the test load increases to 10 T, the settlement of the piles increases suddenly to 31.15 mm, the piles are destroyed. This limited load is used to adjust the load level in testing a group of 4 piles. The group of 4 piles is tested with 2 loading cycles, with the first cycle compressing up to 30 T, unloading and increasing the load of the second cycle compressing to destructive. The test results for 4-pile group show that, with a load of 49.5 T, the pile group has a destructive phenomenon, the settlement has increased suddenly to 35.59 mm. Two load-settlement curves for single piles (cycle 1) and group of 4 piles (cycle 2) are relatively similar, both increase slowly; P-S curve has a small angular coefficient before destructive load.

Limited load capacity for single piles (P_{Ultimate} N°1) is 10 T, for 4-pile group (P_{Ultimate} N°4) is 49.5 T, calculated pile group coefficient is 1.2375. The settlement of single piles is smaller than of the pile group as destructive, these two values of settlement are recorded as relatively large (31.15 mm and 35.59 mm), which is also consistent with the characteristics of friction piles (it is not good for pile tip to rest on the soil layer). Normally for friction piles, in cohesive soil, the pile group coefficient is usually smaller than 1, however in this case of testing, even if it is a friction pile, due to the influence of sand layer, the pile group coefficient is 1.2375 (greater than 1). It can be assessed that sandy soil layer and porous sand layer (layer 3) have affected the load bearing capacity of the pile group. This will be more evident in the results of load distribution by depth.

Fig. 4 shows the axial load transmission curve (F-z) in single piles and pile groups during the loading process. Due to some objective and subjective reasons when installing the gauge and lowering the piles, some gauges have errors during the test and fail to measure the deformation of piles (at the position of 9 m for single piles N°1, position of 3.9 m for piles N°4 C1, N°4 C2 and position of 6.5 m for piles N°4 C3), in these cases, the load transmission curve is assumed to be linear through missing positions.

The F-z curve shows a significant transmission from piles to soil in the range of 0 to 8 m, for both single piles and pile group, the load value at a depth of 8 m is relatively small and close to each other. Thus, the load transmitted down to the pile tip is small, which indicates that most of the load has been distributed through friction into the soil. These results show the tip resistance has been mobilized to a minimum (near zero), and the load imposed on the pile head is distributed (subjected to) by the axial friction resistance component. In the depth from 0 to 3.9 m, the F-z curve has the largest slope, the slope decreases at the area from 3.9 m to 8 m, indicating that friction resistance is mobilized much at the area from 0 to 3.9 m.

Comparing results of vertical force of single pile N°1 and pile N°4 C3 (figures a and d), at the depth of 3.9 m, most of the vertical force values for single piles N°1 are greater than that for pile N°4 C3 ($F_{3.9\text{ m pile N°1}} > F_{3.9\text{ m pile N°4 C3}}$), with the same value of load imposed on the pile head when the pile has not been destroyed (effect load < 100 kN), this shows that friction resistance in the area from 0 to 3.9 m for the pile group has been raised more, reducing the load at the depth of 3.9 m in the pile group. This shows the medium-tight sand layer has increased the friction resistance in the pile group compared to the single piles. Comparing single piles N°1 and N°4 C1, N°4 C2, N°4 C3, at the depth of 8 m, the non-destructive vertical force values of single piles are greater for the piles in group. ($F_{8\text{ m N°1 Pile}} > F_{8\text{ m N°4 C3, N°4 C1, N°4 C2}}$) with the same load imposed on the pile head. This shows the sand layers No. 1 and No. 3 have increased the friction resistance in the pile group, reducing the load at the depth of 8 m larger in single piles, resulting in greater extreme load capacity of the pile group.

Table 1 shows the comparison of axial forces at the depths of 3.9, 6.5 and 8.0 m according to different load levels, in order to compare the load distributed into the soil through friction between single piles and piles in 4-pile group. Due to different load levels between single piles and pile group, in this comparison, the comparison is made between the load level of 20 kN of single piles with the load level of 22.5 kN of piles in the pile group, load levels 40, 60, 80 kN of single piles at the same load level with 45, 67.5, 90 kN of the piles in the corresponding pile group. The results show that with the same load level, vertical force at the same depth, vertical force in the pile group is smaller than that of single piles, this shows that friction resistance in the pile group has been mobilized more in single piles, clarifying the effect of sand layers No. 1 and No. 3 on the load bearing capacity of piles in the pile group.

Table 1. Force along piles at different depths, with different load levels, comparison between single piles N°1 and piles N°4 C1, N°4 C2, N°4 C3

Depth		Single	C1	C2	C3	Single	C1	C2	C3
0	Notation	20	22.5	22.5	22.5	40	45	45	45
3.9	$F_{3.9}$ kN	6.22	-	-	5.65	24.31	-	-	12.44
6.5	$F_{6.5}$ kN	5.65	6.22	2.26	-	18.09	11.31	13	-
8.0	$F_{8.0}$ kN	3.39	3.96	2.83	4.52	13.57	9.05	9.05	9.61

Depth		Single	C1	C2	C3	Single	C1	C2	C3
0	Notation	60	67.5	67.5	67.5	80	90	90	90
3.9	$F_{3.9}$ kN	27.70	-	-	19.79	38.44	-	-	30.53
6.5	$F_{6.5}$ kN	22.05	15.83	25.44	-	31.09	23.74	31.66	-
8.0	$F_{8.0}$ kN	17.53	13.57	19.22	15.83	26.01	19.79	25.44	22.61

4. Conclusions

The result of in-situ tests on single piles and group of 4 piles, with multi-layered foundation, including sandy and clayey soil, for friction piles, based on analysis of the test results, it is possible to give a preliminary conclusion as follows:

- For multi-layered foundation, when there are sand layers in the foundation, the pile group coefficient may be greater than 1, specifically in case of the study, the pile group coefficient is 1.2375.

- For multi-layered foundation, the settlement of pile group is also greater than that of single piles, and the settlement of friction pile is relatively large, specifically in this study, the settlement of single piles as destructive is 31.15 mm and of pile group is 35.59 mm.

- Sand layers in the foundation greatly affect the load capacity of the pile group, increase ability to mobilize friction resistance in the pile group, increase the load capacity of piles and medium-tight sand layer has bigger level of mobilization friction increase.

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